

# The Differing Effects of Regional and General Anaesthesia on Cerebral Metabolism During Carotid Endarterectomy\*

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**Objectives:** To examine the effects of either regional (RA) or general (GA) anaesthesia upon parameters of cerebral metabolism (near infrared spectroscopy, continuous jugular venous oximetry) during carotid endarterectomy.

**Design:** Prospective, non-randomised, observational study.

**Materials:** Sixty-five consecutive patients (33 RA; 32 GA) undergoing carotid endarterectomy.

**Methods:** (i) Near infrared spectroscopy: measurement of concentrations of cerebral oxyhaemoglobin (HbO<sub>2</sub>), deoxyhaemoglobin (HHb) and oxidised cytochrome oxidase (caa<sub>3</sub>). (ii) Continuous jugular venous oximetry: O<sub>2</sub> saturation of jugular venous blood (SjvO<sub>2</sub>). (iii) Stump pressure in internal carotid artery.

**Results:** A reduction in SjvO<sub>2</sub> (RA: 13% (95% CI –3 to 29%) GA: 9% (95% CI –2 to 20%),  $p < 0.08$ ) and a fall in caa<sub>3</sub> levels (RA vs. GA: 25/31 vs. 19/31,  $p = 0.2$ ) was more likely in patients given a RA following application of the carotid clamps. When HbO<sub>2</sub> and caa<sub>3</sub> did fall however spontaneous recovery occurred more often (RA vs. GA; caa<sub>3</sub>: 18/25 vs. 5/19,  $p < 0.005$ ; HbO<sub>2</sub>: 30/31 vs. 4/28,  $p < 0.001$ ).

**Conclusions:** Although GA may offer a degree of cerebral protection by reducing cerebral metabolic rate (lower falls in SjvO<sub>2</sub> and caa<sub>3</sub>) RA preserved cerebral autoregulation as judged by the spontaneous recovery in caa<sub>3</sub> and HbO<sub>2</sub> levels.

**Key Words:** Cerebral metabolism; Carotid endarterectomy; Regional anaesthesia; Near infrared spectroscopy.

## Introduction

Although the majority of vascular surgeons employ a shunt during carotid endarterectomy, there is no evidence that their use, either routinely or selectively, reduces the neurological complications of surgery<sup>1,2</sup> with some 5% of patients developing significant neurological deficits.<sup>3,4</sup> It might be suggested therefore, that additional strategies which may provide cerebral protection during surgery would be advantageous and that these may have applications in other clinical situations of compromised cerebral blood flow. At present, the techniques available for studying cerebral ischaemia rely on drawing inferences about oxygen delivery and utilisation from various haemodynamic and functional parameters and as a result we have only a rudimentary understanding of its pathophysiology. This limits our ability to devise rational methods of cerebral protection. Two new techniques

which make use of developments in fibreoptic and near infrared light technology have become available and these provide direct information on cerebral oxygenation and oxygen metabolism. These are continuous jugular venous oximetry and near infrared spectroscopy.

Continuous jugular venous oximetry relies upon a fibreoptic catheter, positioned in the jugular bulb, which transmits three wavelengths of near infrared light. By measuring absorption of the light a processor calculates the saturation of the jugular venous blood (SjvO<sub>2</sub>) every second. Given a stable haematocrit and position of the oxygen dissociation curve changes in SjvO<sub>2</sub> reflect alterations in the cerebral oxygen supply: oxygen consumption ratio.

Near infrared spectroscopy (NIRS) provides similar information non-invasively<sup>5</sup> making use of the fact that the scalp and skull are relatively transparent to near infrared light and that when subjected to light in the near infrared spectrum (700–1000nm) there are only three light absorbing chromophores in cerebral tissue; deoxyhaemoglobin (HHb), oxyhaemoglobin (HbO<sub>2</sub>) and oxidised cytochrome oxidase (caa<sub>3</sub>). Cerebral concentrations of these molecules are directly

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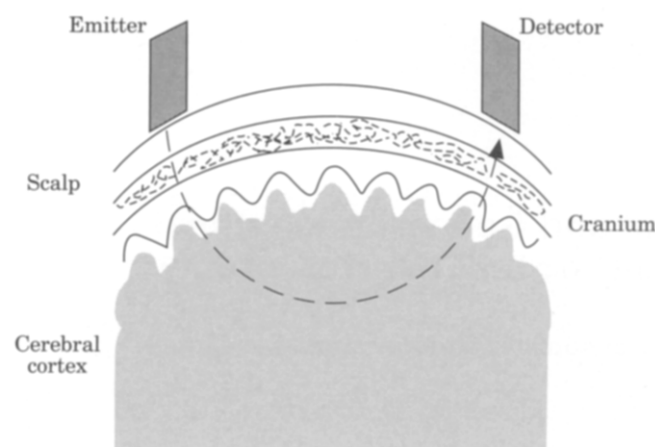


Fig. 1. The principle of near infrared spectroscopy.

influenced by changes in cerebral oxygen supply. A probe incorporating both an emitter and detector window is applied to the forehead, and pulses of low power laser near infrared light of four wavelengths are transmitted into the cerebral cortex (Fig. 1). The light traces a parabolic course through the cerebral tissue and the subsequent detection of transmitted light allows its absorption to be measured. Thus the concentrations of HHb, HbO<sub>2</sub> and caa<sub>3</sub> are calculated.

The aims of this study were thus to examine changes in cerebral metabolism detected by these two new techniques during carotid surgery in patients receiving either a general anaesthetic or regional local anaesthetic nerve block. In the latter group the significance of any changes have been compared with the results of awake neurological testing which is considered to be the "gold standard" for assessing the adequacy of cerebral perfusion during carotid endarterectomy and thus the need for shunt insertion.<sup>6</sup>

## Materials and Methods

### Patients

Sixty-five consecutive patients undergoing carotid endarterectomy were offered regional anaesthesia of whom 30 opted to have a general anaesthetic. A further three patients (2 with a hemiparesis, 1 with dysphasia), who were unsuitable for awake neurological testing also had a general anaesthetic. The remaining 32 patients were operated upon following a regional anaesthetic block.

The two groups were similar in terms of age, sex and the presence of cardiovascular risk factors (Table

Table 1. Demographic details of patients undergoing carotid endarterectomy under either regional and general anaesthesia

	Regional anaesthetic	General anaesthetic
Age (years)	67 (52–77)	69 (45–82)
Sex (M:F)	24:8	19:14
Risk factors		
Tobacco use	19	14
Hypertension	22	22
Diabetes mellitus	4	5
PVD	12	10
Ischaemic heart disease	21	17

1). The severity of their carotid disease, as assessed by duplex colour flow Doppler (Accusson 128XP, California, U.S.A.), was also similar with a mean stenosis of 79% on the ipsilateral side and either 35% (RA) or 40% (GA) in the contralateral internal carotid artery. Both groups exhibited the full range of symptoms associated with their carotid disease (CHAT classification), again with similar frequency (Table 2). The three procedures performed for asymptomatic lesions were all in patients with severe bilateral disease who had undergone previous endarterectomy for a symptomatic contralateral lesion.

### Anaesthetic

All patients received midazolam, 2mg i.v., either prior to induction of general anaesthesia or insertion of the regional local anaesthetic nerve block. The regional anaesthetic consisted of standard deep and superficial cervical plexi blocks<sup>7</sup> using a mixture of 20ml bupivacaine 0.5% and 20ml prilocaine 2%. Patients having a general anaesthetic were induced with fentanyl (100µg), etomidate (0.3mg/kg) and pancuronium (0.07mg/kg), and maintained on a mixture of iso-flourane (0.6–1%), nitrous oxide (60%) and oxygen

Table 2. Severity of carotid disease and indication for surgery in patients undergoing carotid endarterectomy under either regional or general anaesthesia

	Regional anaesthetic	General anaesthetic
Stenosis		
Symptomatic artery	79% (65–90%)	79% (60–99%)
Contralateral artery	46% (0–100%)	35% (0–100%)
Symptoms		
TIA	8	11
CVA (transient)	4	2
CVA (non-disabling)	9	7
CVA (disabling)	0	2
Crescendo TIA	2	2
Amaurosis fugax	7	8
Asymptomatic	2	1

(40%). End-tidal  $p\text{CO}_2$  maintained between 3.8 and 4.2 kP in all patients during general anaesthesia.

In those patients receiving a GA systemic blood pressure was manipulated if it became lower than the preoperative blood pressure during surgery, but in general a non-interventionalist approach was applied.

### *Surgery*

A standard endarterectomy was performed on all patients. The carotid sinus was anaesthetised with 2ml of 1% lignocaine before full mobilisation of the carotid arteries. External, common and internal carotid arteries were clamped sequentially, distal tacking sutures were inserted when necessary and a PTFE patch was used if the internal carotid artery was <5mm in diameter at the distal end of the arteriotomy.

### *Monitoring*

All patients were routinely monitored with intra-arterial BP, pulse oximetry and ECG. In order to ensure that changes in  $p\text{CO}_2$  were not influencing the results of the cerebral monitoring, arterial  $p\text{CO}_2$  was measured in all RA patients on four occasions during the procedure; prior to cross clamping the common carotid artery, 2 min after cross clamping, prior to releasing the clamps and 2 min post clamp release.

Mean stump pressures were measured in the conventional way in all patients and patients who had a regional anaesthetic were subjected to awake neurological testing during the cross clamp period. Awake testing consisted of asking the patients to squeeze a squeaky toy held in the contralateral hand, move the contralateral lower limb, perform simple mental arithmetic, and arithmetic, and to recite their address.

### *Near infrared spectroscopy (NIRS)*

The NIRS probe (Critikon Cerebral Redox Monitor 2001, Johnson and Johnson Medical, Ascot, U.K.) was applied to the forehead over the ipsilateral cerebral hemisphere and secured with adhesive tape prior to induction/insertion of the block. Care is required during positioning of the probe, both to prevent subsequent movement and also exposure of the detector window to extraneous light. The equipment

used in this study provided qualitative (i.e. trends of change) rather than quantitative information.

### *Continuous jugular venous oximetry*

The equipment for continuous jugular venous oximetry (Abbott Critical Care Systems, Chicago, U.S.A.) consists of an optical module which emits near infrared light via a fiberoptic catheter and a processor which calculates changes in the jugular venous oxygen saturation ( $\text{SJvO}_2$ ). The fiberoptic catheter was inserted into the ipsilateral internal jugular vein via a 16G needle mounted cannula and fixed in position with a 5/0 prolene purse-string suture before dissection of the carotid arteries. Positioning of the tip of the fiberoptic catheter in the jugular bulb is crucial and this was achieved by passing the catheter cephalad through the cannula until it abutted the base of the skull. The catheter was then withdrawn approximately 1cm to obtain a good light signal. Blood samples were withdrawn from a parallel channel on four occasions during each procedure and the saturations measured using a co-oximeter to check the calibration of the Oximetrix System.

This equipment provides quantitative data (normal  $\text{SJvO}_2$  levels: 60–70%) with a rise in  $\text{SJvO}_2$  indicating that there is excess oxygen supply over demand (luxury perfusion,  $\text{SJvO}_2 > 75\%$ ). When the oxygen supply is inadequate  $\text{SJvO}_2$  will fall and a reduction to <40% suggests global ischaemia.<sup>8</sup>

All NIRS,  $\text{SJvO}_2$  and haemodynamic data were stored on a PC using custom built software (Johnson and Johnson Medical, Ascot, U.K.) with data points taken every second.

### *Shunting*

Patients who received a GA were shunted if the mean stump pressure was <50mm Hg, whilst the primary indication for shunt insertion in patients in the RA group was a deterioration in cerebral function or the level of consciousness as assessed by awake neurological testing.

### *Statistics*

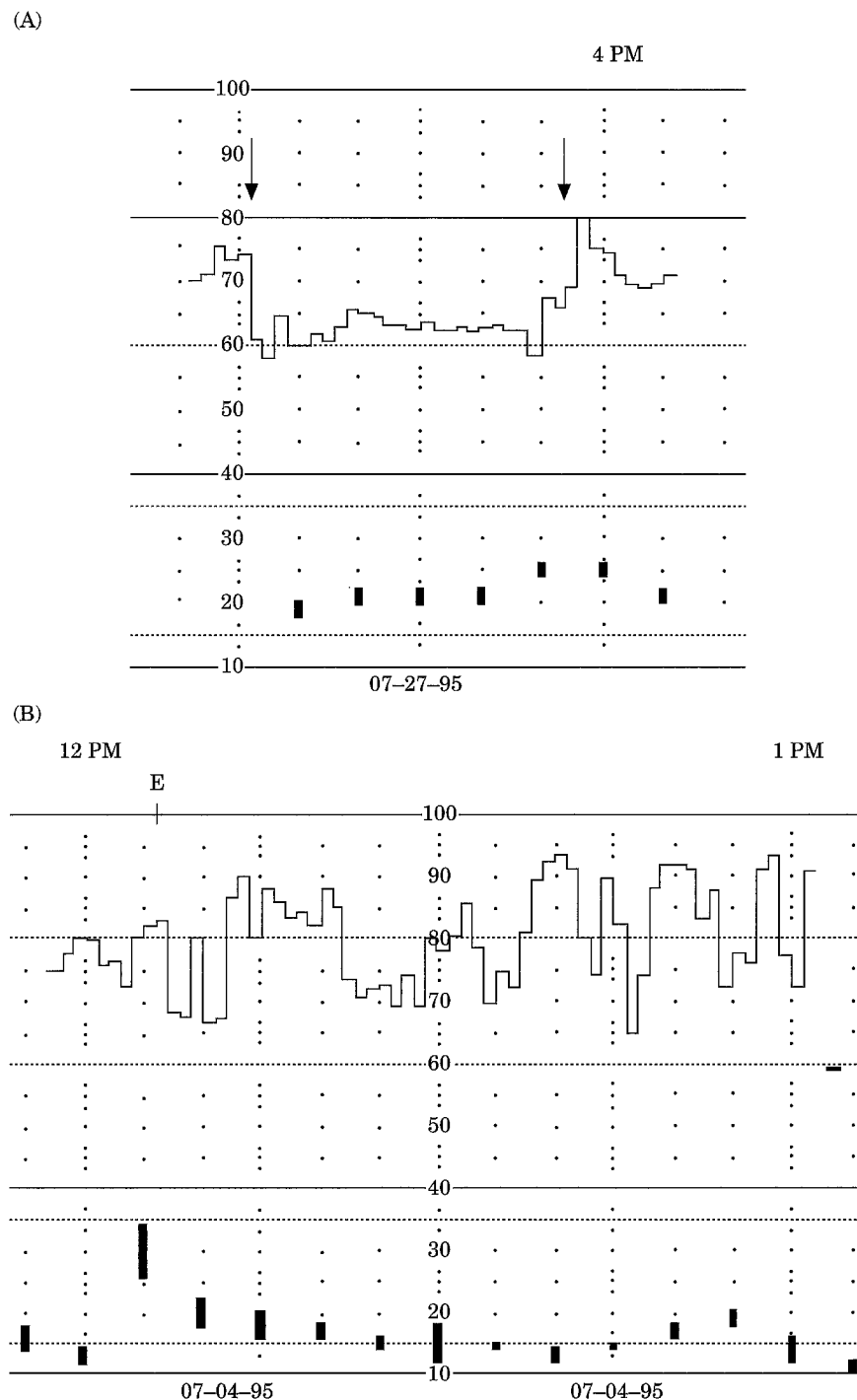
Numerical data were compared using the student *t*-test and group differences by the Chi-squared test.

## Results

### *Continuous jugular venous oximetry*

Jugular venous traces vary in quality (Fig. 2), and

although there are no given criteria for acceptability, a satisfactory trace for the purposes of this study was defined firstly as one in which three of the four calibration blood samples were within 5 percentage points of the saturation displayed by the oximetry



**Fig. 2.** Continuous jugular venous oximetry: comparison of acceptable (A) and unacceptable (B) traces. (A): The satisfactory trace shows a fall in  $SjvO_2$  on crossclamping (first arrow) and remains low until the clamps are released (second arrow). A brief period of hyperaemia follows. (B): An unacceptable trace; unstable signal with frequent sudden changes of  $> 10\%$  points.

**Table 3. Results for continuous jugular venous oximetry (SJvO<sub>2</sub>) in patients undergoing carotid endarterectomy under either regional or general anaesthesia**

	Regional anaesthetic	General anaesthetic	
Acceptable trace	22	26	N.S.
Fall after CCA cross-clamp	21/22	25/26	N.S.
SJvO <sub>2</sub> pre cross-clamp (95% CI)	77% (54–100)	72% (48–96)	<i>p</i> =0.1
SJvO <sub>2</sub> fall post CCA cross-clamp (95% CI)	13% (–3 to 29)	9% (–2 to 20)	<i>p</i> =0.08

system, and secondly if there were fewer than six sudden changes of >10% in SJvO<sub>2</sub> during the course of the procedure. Such changes occur when the tip of the probe rests against the wall of the jugular bulb. Thus 48 of 65 jugular venous traces were adequate for analysis (Table 3).

Mean baseline SJvO<sub>2</sub> was 77% in the RA group and 72% in the GA group (*p* = 0.1). SJvO<sub>2</sub> fell in 46 patients following cross clamping of the common carotid artery returning to baseline levels when a shunt was inserted or following release of the cross clamps (Fig. 2B). The mean fall in SJvO<sub>2</sub> in the RA group was 13% (95% CI –3 to 29%), and 9% (95% CI –2 to 20%) in the GA group (*p* = 0.08).

#### *Near infrared spectroscopy*

Three traces were uninterpretable due to probe failure. Typical traces obtained from patients having either a GA or RA are shown in Fig. 3 and the results of niroscopy summarised in Table 4. HbO<sub>2</sub> fell in nearly every patient, regardless of anaesthetic technique, when the external carotid artery was clamped and again when the common carotid artery was cross clamped. However whilst HbO<sub>2</sub> levels recovered spontaneously within 3min in 22/30 patients who had a RA the same phenomenon occurred in only 4/28 of those having a GA (*p* < 0.001). A fall in caa<sub>3</sub> following crossclamping of the common carotid artery, indicating cerebral, cellular ischaemia, occurred in a greater proportion of patients who had a RA than in those having a GA. (25/31 *vs.* 19/31, *p* = 0.2). As with the HbO<sub>2</sub> traces caa<sub>3</sub> recovered spontaneously in most patients having a RA but in only a small proportion of patients under GA (18/25 *vs.* 5/19, *p* < 0.005).

#### *SJvO<sub>2</sub> vs. HbO<sub>2</sub>*

Whilst small changes in HbO<sub>2</sub> were observed in the

majority of patients following cross clamping of the external carotid artery changes in SJvO<sub>2</sub> were less frequent. This suggests that there is an extracerebral contribution to the changes in oxygenation measured by the Critikon Cerebral Redox Monitor. However there was close symmetry between subsequent changes in HbO<sub>2</sub> and SJvO<sub>2</sub> following clamping of the common carotid artery in 45 of the 48 traces in which a comparison was possible (Fig. 3) and it is reasonable to conclude that changes in HbO<sub>2</sub> reflect alterations in cerebral oxygenation.

In the patients in whom a fall in SJvO<sub>2</sub> also occurred following application of the external carotid artery clamp it is likely that this artery was providing a significant collateral supply to the brain.

#### *Systemic blood pressure, stump pressure and shunt insertion*

These results are summarised in Table 5. Whilst the mean pre-operative blood pressure was the same in both groups it was persistently higher in patients with a RA prior to application of the vascular clamps (*p* < 0.01). Similarly a further rise occurred following clamping of the common carotid artery in these patients whilst it did not change in GA patients (*p* < 0.001). These differences almost certainly account for the non-significant difference in mean stump pressure between the two groups.

Whilst the latter will, at least in part, reflect the differing frequency with which a shunt was inserted the criteria upon which this was dependent varied between the groups. Detailed information regarding changes in metabolic and haemodynamic parameters for RA patients in whom a shunt was required are shown in Table 6.

#### *pCO<sub>2</sub>*

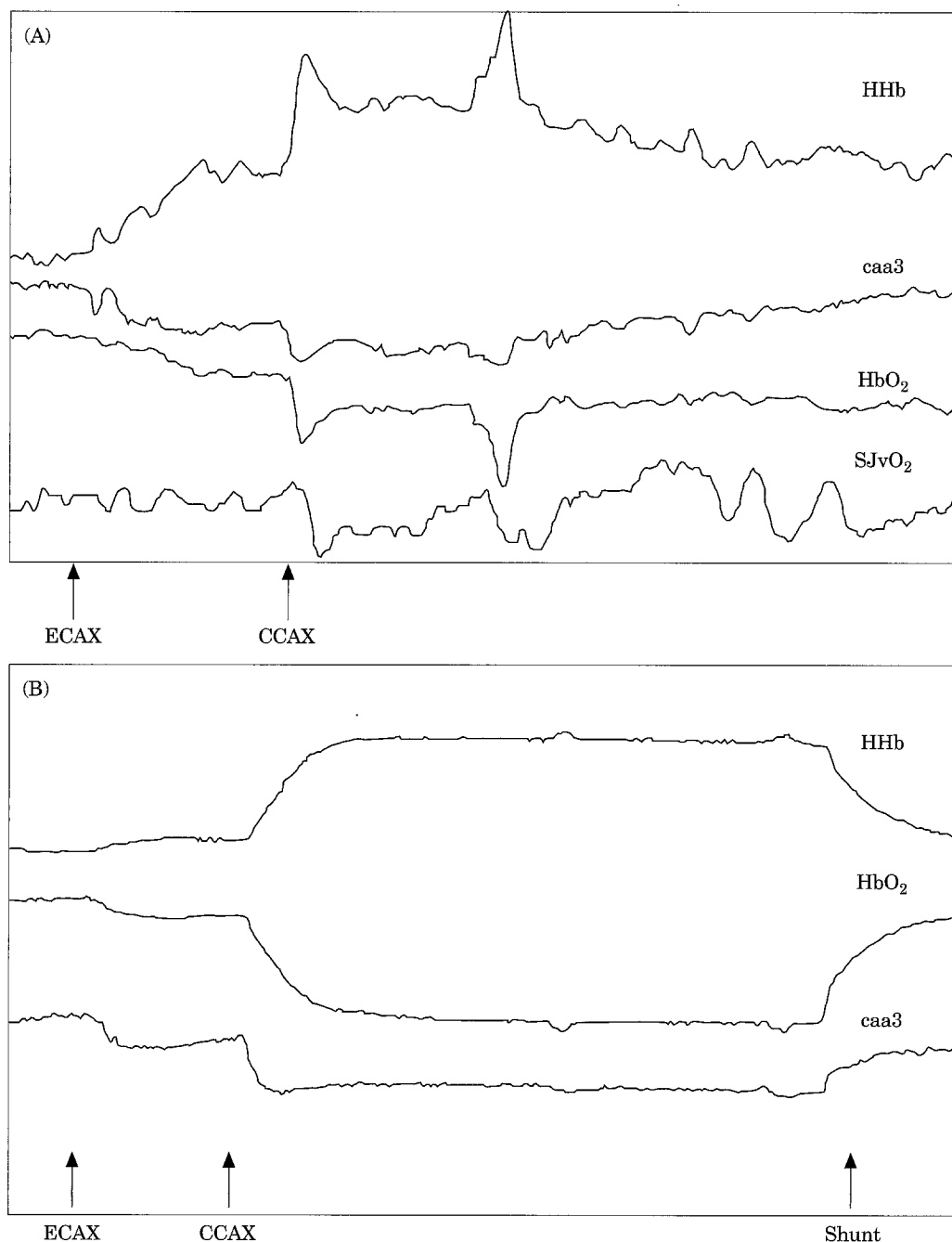
Arterial pCO<sub>2</sub> remained constant in all patients receiving a RA throughout the operative period. Thus alterations in pCO<sub>2</sub> were not responsible for changes in the parameters of cerebral metabolism in these patients.

#### *Outcome of surgery*

Of the patients undergoing carotid endarterectomy

under GA one had a significant neurological event (left hemiparesis). Whilst no neurological complications occurred in the RA group one patient from this cohort died at 48h following a myocardial infarction.

This patient had previously been declined surgery for an abdominal aortic aneurysm on the grounds of his cardiac status.



**Fig. 3.** Typical NIRS traces from patients undergoing carotid endarterectomy under either regional (A) or general (B) anaesthesia. (A): Note the falls in HbO<sub>2</sub> and caa<sub>3</sub> on crossclamping the external carotid artery (ECA X) and then further falls on cross-clamping the common carotid artery (CCA X). (B): Note the small falls in HbO<sub>2</sub> and caa<sub>3</sub> on cross clamping the external carotid artery (ECA X), with further falls on cross clamping the common carotid artery (CCA X). Neither HbO<sub>2</sub> nor caa<sub>3</sub> recover until a shunt is inserted. Both caa<sub>3</sub> and, to a lesser extent, HbO<sub>2</sub> show spontaneous recovery towards baseline levels consistent with autoregulation occurring within 3 min. Note also the close symmetry between the SjvO<sub>2</sub> and HbO<sub>2</sub> traces.

**Table 4. Results of niroscopy in patients undergoing carotid endarterectomy under either regional or general anaesthesia**

	Regional anaesthetic	General anaesthetic	
Acceptable trace	31/32	31/33	N.S.
HbO <sub>2</sub>			
Fall on CCA cross-clamp	30/31	28/31	N.S.
Spontaneous recovery*	22/30	4/28	<i>p</i> <0.001
Caa <sub>3</sub>			
Fall on CCA cross-clamp	25/31	19/31	<i>p</i> =0.2
Spontaneous recovery*	18/25	5/19	<i>p</i> <0.005

\*Recovery within 3 min of applying clamps.

## Discussion

The principle of measuring the saturation of jugular venous blood to assess cerebral perfusion is not new although previous studies have all relied upon the measurement of O<sub>2</sub> saturation in samples collected intermittently from the internal jugular vein.<sup>9,10</sup> Continuous jugular venous oximetry has obvious advantages in that it provides real-time measurement of SJvO<sub>2</sub> and can thus be used to record changes in a dynamic situation. The Oximetrix 3 System has been extensively employed in patients with head injuries<sup>8</sup> and its deficiencies, in particular its sensitivity to changes in catheter position, are well documented.<sup>11</sup> It is largely as a result of the catheter's sensitivity to positional changes that a proportion of the SJvO<sub>2</sub>

**Table 5. Mean systemic blood pressure, mean stump pressure (mm Hg, 95% CI) and frequency of shunt insertion in patients undergoing carotid endarterectomy under either regional or general anaesthesia**

	Regional anaesthetic	General anaesthetic	
Shunt inserted (%)	5/32 (16%)	21/33 (64%)	<i>p</i> <0.001
Stump pressure	51 (0–102)	44 (6–86)	<i>p</i> =0.24
Preoperative BP	103 (87–119)	105 (85–133)	N.S.
Pre-clamping BP	111 (71–151)	99 (65–133)	<i>p</i> <0.01
Change in BP on cross-clamping	14 (–10 to 38)	0 (–14 to 14)	<i>p</i> <0.001

**Table 6. Haemodynamic and cerebral metabolic data in patients who did not tolerate common carotid artery clamping during carotid endarterectomy under regional anaesthesia**

	Stump pressure (mean mmHg)	SJvO <sub>2</sub> change (% points)	Spon-taneous recovery caa <sub>3</sub>	BP change on cross-clamping
Patient 1	38	–15	no	0
Patient 2	30	–10	no	0
Patient 3	34	–20	yes	+20
Patient 4	22	–20	no	0
Patient 5	22	no trace	yes	+5

traces in this study were considered uninterpretable and it is not surprising that the catheter was inadvertently moved on occasions during surgery. These technical difficulties may reduce the effectiveness of this technique as a means of selecting patients for shunt insertion should it eventually appear appropriate to do so.

There is also a theoretical problem in drawing conclusions from the SJvO<sub>2</sub> measurements when the cerebral ischaemia is principally hemispheric. Some 80–90% of the cerebral venous effluent drains via the right internal jugular bulb with free communication between both right and left sigmoid sinuses.<sup>11,12</sup> Thus the blood in the ipsilateral jugular bulb will comprise a variable mixture of venous blood from both the "ischaemic" hemisphere and the "non-ischaemic" hemisphere and this may have an unpredictable effect on SJvO<sub>2</sub> levels. However in any given patient a state of steady equilibrium should be reached and changes in SJvO<sub>2</sub> should be directly proportional to changes in the saturation of blood in the cerebral tissue. The trend in SJvO<sub>2</sub> can therefore be used to validate the claim that the Critikon Cerebral Redox Monitor is measuring similar trends in cerebral HbO<sub>2</sub>.

NIRS, on the other hand, has the advantage of being both noninvasive and of assessing the balance of oxygen supply to demand in cerebral tissues directly. Furthermore it evaluates changes in the cerebral concentration of cytochrome oxidase (caa<sub>3</sub>). Caa<sub>3</sub> is the last link in the mitochondrial electron transport chain and is responsible for >90% of the cellular oxygen consumption (Fig. 4). The concentration of oxidised caa<sub>3</sub> should therefore be a more accurate measure of the adequacy of cellular oxygen delivery than the relative concentrations of HHb and HbO<sub>2</sub> since changes in these parameters reflect alterations in oxygen extraction which is a normal homeostatic mechanism rather than necessarily representing tissue ischaemia.

The feasibility of using NIRS to assess cerebral oxygenation was first described by Jobsis *et al.* in 1977,<sup>13</sup> although a combination of both theoretical and practical difficulties have previously prevented its widespread application. These difficulties include the generation of qualitative rather than quantitative data and the related problem of deleting the extracerebral contribution to observed changes.<sup>6</sup> The instrument used in this study does not attempt to perform either of these functions and therefore generates trend information only although the latter problem has been overcome by the sequential application of the external and common carotid artery clamps. This allows the assumption that all changes recorded following clamping of the internal carotid artery reflect changes

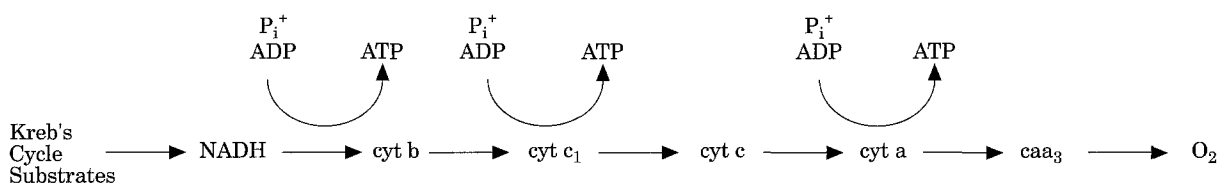


Fig. 4. The role of cytochrome oxidase ( $caa_3$ ) in oxidative metabolism (Kreb's cycle and the mitochondrial electron transport chain). Nicotine amide dinucleotide, reduced (NADH), adenosine dinucleotide (ADP), free phosphate ( $P_i$ ), adenosine trinucleotide (ATP).

in cerebral oxygenation. The close symmetry between the  $HbO_2$  and  $SjvO_2$  traces during internal carotid artery occlusion confirms the validity of this premise.

The potential difficulties in measuring trends in the redox state of  $caa_3$  have been highlighted by Cooper *et al.*<sup>14</sup> These relate both to the low concentration of  $caa_3$  in cerebral tissue and the use of complex algorithms to deconvolute changes in the much higher concentrations of  $HbO_2$  and HHb. In addition the redox state of  $caa_3$  may depend upon a number of variables other than the availability of oxygen (pH, membrane potential, concentration of ADP).<sup>14</sup> However these variables are unlikely to have a significant influence during carotid endarterectomy and thus assuming that the algorithms are adequate, it is reasonable to assume that a fall in  $caa_3$  represents cerebral ischaemia.

Our results demonstrate that application of a clamp to the internal carotid artery results in increased oxygen extraction (fall in  $HbO_2$  and  $SjvO_2$ ) in almost every patient, regardless of anaesthetic technique, confirming that this manoeuvre reduces cerebral blood flow. These findings are consistent with those of two other reports in which near infrared spectroscopy has been used to monitor cerebral perfusion during carotid endarterectomy under GA.<sup>10,15</sup> However the proportion of patients in whom  $caa_3$  fell during GA was less than in patients who had a RA. Similarly there is a suggestion that  $SjvO_2$  changes were lower following a GA. Although these differences were not significant they would be consistent with the view that isoflourane (given to maintain GA) reduces the cerebral metabolic rate and hence oxygen demand.<sup>16</sup>

Although a previous study<sup>15</sup> involving only 11 patients failed to demonstrate any change in  $caa_3$  levels during surgery this may reflect the sensitivity and calibration of the instrument used in the study and may also related to the technical difficulties associated with NIRS that have been alluded to above.

Our results demonstrate that both  $HbO_2$  and  $caa_3$  fell in most patients following application of the clamp to the common carotid artery. Whilst they recovered spontaneously in the majority of patients having a RA

this was rarely the case in patients undergoing surgery under a GA. These findings were highly significant and confirm that cerebral autoregulation is preserved by RA but is impaired by a GA. Cerebral autoregulation is a catch all term that can be applied to any mechanism that returns cerebral blood flow towards baseline levels. It is clear from our data that mean systemic blood pressure was higher throughout the operative period when carotid endarterectomy was performed under RA. Furthermore there was a significant increase in mean systemic blood pressure when the common carotid artery cross clamp was applied. Although a more detailed analysis of this data is required, it would seem reasonable to suggest that in patients who had a RA the increase in systemic blood pressure may contribute to the observed autoregulation. The mechanism by which these changes in blood pressure occur remains obscure but since the carotid sinus nerve was anaesthetised in all patients it is likely that they involve cerebral perfusion receptors of some kind which are either damped or blocked by isoflourane.

In summary therefore whilst both cerebral hypoxia ( $HbO_2$ ,  $SjvO_2$ ) and cellular ischaemia ( $caa_3$ ) may occur less often during an isoflourane based GA a spontaneous recovery in the direct parameters of these events ( $HbO_2$ ,  $caa_3$ ) within 3 min of cross-clamping of the common carotid artery was more likely in the patients who had a RA. As a result a greater proportion of GA patients demonstrated evidence of persistent cerebral ischaemia after this time. In this series one patient in the GA group developed a left hemiparesis following surgery and although there were no significant neurological complications in the RA group this difference is clearly not significant. However if it is believed that preservation of cerebral autoregulation by a RA may provide better cerebral protection than GA, then this will almost certainly require assessment by detailed neuropsychometric studies.

A shunt was used in five patients in the RA group because of a deterioration in conscious level. In three of these there was no increase in systemic blood pressure following application of the vascular clamps



or evidence of autoregulation as judged by a recovery in  $\text{caa}_3$  levels. In the other two patients, in whom blood pressure did increase and autoregulation appeared to occur, the patients became drowsy 15 min into the cross-clamp period without a reduction in blood pressure. However secondary, dramatic, falls in  $\text{SjvO}_2$ ,  $\text{HbO}_2$  and  $\text{caa}_3$  occurred. No definite explanation can be offered for these events although similar delays between application of the vascular clamps and loss of consciousness have been reported elsewhere.<sup>17</sup> It is clear however that the stump pressure in these patients was low and the delay in the development of neurological signs may represent a state of sub-acute ischaemia.

It is clear that both the rise in mean systemic blood pressure and the autoregulatory response are specific to patients who have a RA and thus their absence cannot be used as criteria for the insertion of shunts in patients who have an isoflurane based GA. It is possible however that other anaesthetic agents may preserve cerebral autoregulatory responses and this requires further investigation. Similarly further studies using the next generation of near infrared spectroscopy instruments, which provide both quantitative information and delete the extracerebral contribution to changes in the measured parameters, may provide objective and reliable criteria for the insertion of a shunt during carotid endarterectomy.

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